Application of Goal Programming Integrated Multi-Criteria Decision Making Approaches for the Stock Area Selection Problem of an Automotive Company

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***Abstract*— This study considers a stock area selection problem (SASP) of an automotive company which includes limited space. The SASP of the company consists of alternative locations which have different technical features and some specific criteria to select the locations. The aim of the problem is to find best stock areas from the alternatives that will be constructed. In order to solve the SASP of the company four different approaches are taken into account where each approach integrates a fuzzy multi-criteria decision making (MCDM) method within a preemptive goal programming (PGP) model. The main difference between the proposed approaches is the fuzzy MCDM methods used in the solution procedure where the considered methods are a fuzzy AHP (Analytic Hierarchy Process) method, a fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Situation) method, a fuzzy PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method, and a fuzzy VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje in Serbian) method. Each solution approach consist of two stages where the alternatives are evaluated with respect to qualitative criteria by using fuzzy MCDM methods, and then PGP model is operated for quantitative criteria and the alternative scores obtained in the first stage. As a result of the computational application of the proposed solution methodology, the best alternatives are selected to construct in the company by comparing the results of four solution approaches.**

***Keywords*—** *Stock area selection, multi-criteria decision making, fuzzy set, goal programming, case study*

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1. Introduction

Facility layout planning is a critical issue for the companies because of its directly effects on the operational productivity and efficiency of a facility [1]. At this stage, managers have to take into account various criteria so as to obtain best layout plan where most of them cannot be measured exactly because of their uncertainty. Due to its significant impacts on the performance of manufacturing systems, the facility layout planning problem with multiple criteria has been commonly studied by researchers [2]. Moreover, several approaches are proposed for different type of facility layout problems, which aims to find effective solutions by satisfying a set of constraints or performance objectives. Also it is shown that a good layout design obtained with an appropriate solution approach contributes to the overall efficiency of operations by having a great potential to reduce until 50% the total operating costs [3].

In this study, a stock area selection problem (SASP) of an automotive company is considered which aims to evaluate best selection from the alternatives by considering both qualitative and quantitative criteria. In order to solve the SASP of the company, this study introduces four different solution approaches, where each approach integrates a fuzzy multi-criteria decision making (MCDM) method within a preemptive goal programming (PGP). In this context, the considered MCDM methods are fuzzy AHP (Analytic Hierarchy Process) method, fuzzy TOPSIS (Technique for Order Preference by Similarity to

Ideal Situation) method, fuzzy PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method, and fuzzy VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje in Serbian) method. For each method, the measurement of the alternatives and decision making process are carried out into two stages. First, qualitative criteria are taken into account according to the selected fuzzy MCDM method. Then the PGP model is operated by considering the alternative scores obtained in the first stage and other quantitative constraints. Finally, the best location set is selected by comparing the results of four solution approaches. In computational studies, the proposed methods are implemented to the real-life problem of the company which consist of eight qualitative and three quantitative criteria to select best location set from five alternative areas.

The rest of the paper is organized as follows: Section 2 presents the literature review part for the fuzzy AHP (F-AHP), fuzzy TOPSIS (F-TOPSIS), fuzzy PROMETHEE (F-PROMETHEE), fuzzy VIKOR (F-VIKOR) and PGP methods. Section 3 describes the problem and Section 4 introduces the proposed solution methodology. The application of the proposed solution methodology to case study is given in Section 5. Finally, conclusions and discussions are presented in Section 6.

2. Literature Review

Most of the studies in literature have been considered the location selection or facility layout problem based on the quadratic assignment problem with an objective function to minimize total transportation or cost maximize total closeness ratings. Moreover, due to the complexity of the problem, various heuristic and meta-heuristic approaches are proposed to solve problem [4], [5]. However, stock area selection decision involve several qualitative and quantitative criteria and it is often necessary to select among possibly conflicting and multiple objectives. Therefore, the multiple criteria decision making becomes a useful approach for solving this kind of problem where AHP, TOPSIS, PROMETHEE and VIKOR are the most commonly used MCDM methods.

AHP is firstly introduced by ref. [6], [7] as a model and then applied widely to several complex decision problems, such as supplier selection [8]-[10], technology investment [11], [12], project management [13]-[15], energy policy [16], [17], location design [18], [19]. TOPSIS, proposed by ref. [20], choose alternatives that have the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal solution. TOPSIS is a widely adopted decision support technique in management research. For example, ref. [21] applied TOPSIS to evaluate the performances of firms by using the financial tables. These firms are examined and assessed in terms of ten financial ratios. Ref. [22] proposed a TOPSIS based design of experiments to assess company ranking and tested their method by case studies. The PROMETHEE method is a class of outranking method for a finite set of alternative actions to be ranked and selected among criteria [23]. This method is introduced by Brans et al. in 1984 and applied to many problem from various fields [24]-[26]. The VIKOR method developed by ref. [27] determines compromise solutions for a problem with conflicting criteria, which can help to the decision makers in order to reach a final decision. A number of applications using VIKOR can be found in the literature [28], [29].

In addition to the basic structures of the MCDM methods, fuzzy set theory combined with MCDM methods has been extensively used to deal with uncertainty, subjectivity, and ambiguity in the decision process, where F-AHP, F-TOPSIS, F-PROMETHEE and F-VIKOR are the most widely used approaches [30]-[32]. Another advanced solution methodology in this field is integrating MCDM methods with goal programming (GP). GP, originally introduced by ref. [33], is a mathematical approach that capable of handling multiple objectives with a priori articulation of the preference information [34]. MCDM techniques can be used as an effective tool together or combined with GP to take into account both qualitative and quantitative criteria. There are various studies in the literature which use the MCDM methods and GP together or MCDM methods and GP together under fuzzy environment [35]-[45]. One of the main approaches in GP is Preemptive GP, also known as lexicographic GP, in which the first-priority goals are optimized before lower priority goals are even considered.

3. Problem Description

This study is carried out in a paintshop department of an automotive company. Besides the painting process of the carbodies, this department also includes various operations to avoid corrosion on body, outflow at joining surfaces, noise arisen by vibration, etc. The carbodies are transported between the stations for these operations on a conveyor carrier system via an auxiliary equipment called as "luge" where the total number of luges in department is 579. After the painting operations, the luges loaded with a painted carbody are transferred from paintshop to temporary storage area for assembly process. According to the assembly order, the painted carbodies are sent to the assembly department by switching the paintshop luge with an assembly luge. At this stage, the idle luges are transferred back to the initial station of the department if a new carbody arrives to the paintshop department. Otherwise, the idle luges are moved manually by workers to the luge stocking area whose capacity is 111 or to any location if the stocking area is full. In addition to the inefficient workforce utilization, these movements also cause a physical and chemical deformation on the luges, which exposes additional cost for the firm. Because of the existing stocking area is insufficient and manual movements deforms the luges, the firm wants to construct two new stocking areas by choosing from five alternative locations (A1, A2, A3, A4, and A5) with different capacities and properties. In order to make best selection to construct stocking areas, the firm described various criteria to evaluate the ratings of the alternatives which are categorized into two groups: qualitative and quantitative criteria. For the quantitative criteria, investment cost, stock area capacity and depreciation of the investment are considered, while the qualitative criteria are described as follows:

- Criticality (C1)
- Location (C2)
- Feasibility (C3)
- Availability (C4)
- Maintenance (C5)
- Construction period (C6)
- Processing time for stocking (C7)
- Energy requirement (C8)

4. Proposed Methodology

In order to solve the SASP of the company, four fuzzy MCDM methods integrated within a PGP are introduced by using F-AHP, F-TOPSIS, F-PROMETHEE, and F-VIKOR. Each solution approach consists of two stages. In the first stage, a fuzzy MCDM method is operated for the qualitative criteria with linguistic definitions. Following the MCDM process, the PGP model is performed by considering the alternative weights obtained in the first stage and other quantitative constraints. Figure 1 represents the framework of the proposed solution procedure for the SASP. The details of the solution methodology for the SASP are given in the following subsections.

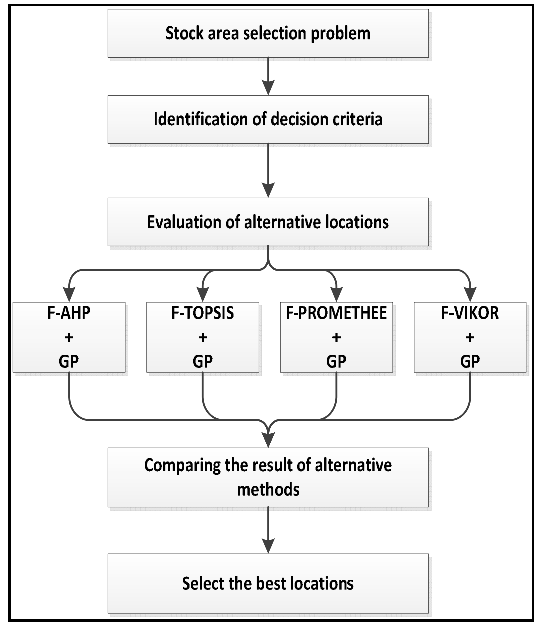

Figure 1: The framework of the proposed solution procedure

4.1. Fuzzy AHP

The F-AHP method, which is widely used as a decision making procedure in various MCDM problems, embed the fuzzy theory to basic AHP methods. Distinctly from the AHP, this method uses linguistic variables to take the pair-wise comparisons of different alternatives with respect to various criteria. The scores of each alternative are calculated after weighting both criteria and the alternatives by using the fuzzy numbers. In this study, the F-AHP method proposed by ref. [46] which utilizes a triangular fuzzy set in its process is used for the first solution approach. Table 1 shows the triangular fuzzy scales applied for the SASP [47].

4.2. Fuzzy TOPSIS

For the second solution procedure, the F-TOPSIS method proposed by ref. [48] is considered to solve

SASP. The TOPSIS method differentiate between the benefit and the cost category and selects the solutions based on the positive and negative ideal solutions. In addition to the TOPSIS method, the F-TOPSIS method allows the decision maker to incorporate unquantifiable information, incomplete information and non-obtainable information which cope with the uncertainty and imprecision related with representing decision maker's observations to crisp values [49]. In this method, the linguistic variables are used by decision makers to assess the weights of the criteria and the ratings of the alternatives. These linguistic variables proposed by ref. [48] are expressed with triangular fuzzy numbers as shown in Table 2.

Table 1: Linguistic variables used for the F-AHP

Linguistic Definition	Fuzzy Triangular Scale	Reciprocal of the Scale
Equally Important (E)	(1, 1, 1)	(1/1, 1/1, 1/1)
The Intermittent Value (EW)	(1, 2, 3)	(1/3, 1/2, 1/1)
Weakly Important (W)	(2, 3, 4)	(1/4, 1/3, 1/2)
The Intermittent Value (WF)	(3, 4, 5)	(1/5, 1/4, 1/3)
Fairly Important (F)	(4, 5, 6)	(1/6, 1/5, 1/4)
The Intermittent Value (FS)	(5, 6, 7)	(1/7, 1/6, 1/5)
Strongly Important (S)	(6, 7, 8)	(1/8, 1/7, 1/6)
The Intermittent Value (SA)	(7, 8, 9)	(1/9, 1/8, 1/7)
Absolutely Important (A)	(9, 9, 9)	(1/9, 1/9, 1/9)

Table 2: Linguistic variables used for the F-TOPSIS

Linguistic Definition	Fuzzy Triangular Weights
Very Low (VL)	(0.0, 0.0, 0.1)
Low (L)	(0.0, 0.1, 0.3)
Medium Low (ML)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium High (MH)	(0.5, 0.7, 0.9)
High (H)	(0.7, 0.9, 1.0)
Very High (VH)	(0.9, 1.0, 1.0)

4.3. Fuzzy PROMETHEE

The F-PROMETHEE method, which is the combination of the PROMETHEE method and fuzzy numbers, is considered as a third alternative method to solve SASP. The F-PROMETHEE method is very similar to PROMETHEE method, where the main difference is that fuzzy number logic is included in the methodology of it solely [50]. In this study, the F-PROMETHEE is applied for the SASP as it is proposed by ref. [51] in which all calculations and operations described in principles of PROMETHEE method. By forming the decision maker's opinions as fuzzy numbers the alternatives are ranked after the evolution of the F-PROMETHEE steps. The linguistic variables used in the F-PROMETHEE are shown in Table 3 which are proposed by ref. [51].

Table 3: Linguistic variables used for the F-PROMETHEE

Linguistic Definition	Fuzzy Triangular Weights
Strongly Disagree (SDA)	(0.00, 0.00, 0.15)
Disagree (DA)	(0.00, 0.15, 0.39)
Little Disagree (LDA)	(0.15, 0.30, 0.50)
No Comment (NC)	(0.30, 0.50, 0.65)
Little Agree (LA)	(0.50, 0.65, 0.80)
Agree (A)	(0.65, 0.80, 1.00)
Strongly Agree (SA)	(0.80, 1.00, 1.00)

4.4. Fuzzy VIKOR

The F-VIKOR method, which is the fourth alternative method for the first stage of the solution methodology, proposed by ref. [52] is used. The considered F-VIKOR method is the extension of the VIKOR method with a mechanism to extract and deploy objective weight considering the fuzzy numbers. Distinctly from the previous three approaches the F-VIKOR defines the linguistic terms by using the trapezoidal fuzzy numbers which are represented in Table 4. Considering the fuzzy trapezoidal numbers, a compromise solution is introduced at the end of the F-VIKOR steps. Due to the F-VIKOR determines the rankings of the alternatives with respect to ascending order of their scores, a normalization procedure is applied to F-VIKOR solution to use these values in PGP.

Table 4: Linguistic variables used for the F-VIKOR

Linguistic Definition	Fuzzy Trapezoidal Weights
Very Low (VL)	(0.0, 0.0, 0.1, 0.2)
Low (L)	(0.1, 0.2, 0.2, 0.3)
Medium Low (ML)	(0.2, 0.3, 0.4, 0.5)
Medium (M)	(0.4, 0.5, 0.5, 0.6)
Medium High (MH)	(0.5, 0.6, 0.7, 0.8)
High (H)	(0.6, 0.7, 0.7, 0.8)
Very High (VH)	(0.8, 0.9, 1.0, 1.0)

4.5. Goal programming

After the first stage of the proposed solution methodology, a PGP is employed, which takes into account the outputs of the MCDM method as a special constraint in model. The aim of the model is to find best selection that minimizes total derivation from the target values. The notations and model formulation are given as follows:

Parameters

G set of goals

A set of alternatives

P_k priority level ($P_1 > P_2 > .... >>> P_k$)

t_i target value of the goal i; $\forall i \in G$

a_{ij} coefficient of alternative i for goal j in technological constraints; $\forall i \in G; \forall j \in A$

s the number of alternatives in which a choice have to made

Decision Variables

x_j is a binary variable and equal to 1 is if the alternative j is constructed as a stock area, otherwise 0; $\forall j \in A$

d_i^+ is a positive variable and indicates the positive deviations from goal i; $\forall i \in G$

d_i^- is a positive variable and indicates the negative deviations from goal i; $\forall i \in G$

Model

$$Min \quad Z = \sum_k \sum_{i \in G} P_k (d_i^- + d_i^+) \tag{1}$$

Subject to

$$\sum_{j \in A} a_{ij} x_j - d_i^+ + d_i^- = t_i \qquad \forall i \in G \tag{2}$$

$$\sum_{j \in A} x_j = s \tag{3}$$

$$x_j \in \{0,1\} \qquad \forall j \in A \tag{4}$$

$$d_i^+, d_i^- \geq 0 \qquad \forall i \in G \tag{5}$$

Equation (1) identifies the objective function which aims to minimize total weighted deviations from the goals. Equation (2) describes the goals of the problem and also computes the positive and negative deviations from the goals. Equation (3) ensures that the selected alternative area to be constructed must be equal to s. Equation (4) and (5) describe the binary and positive variables, respectively.

5. Application of the Proposed Methodology

In order to identify the best two alternatives for the company, the proposed solution methodology is applied for the SASP by considering the qualitative and quantitative criteria described above. For these computations, the required entries of the fuzzy MCDM approaches (i.e. comparisons, ratings, weights etc. for the alternatives and criteria) are formed by applying an interview to three decision makers of the company, which are represented in Appendix A, B, C and D for F-AHP, F-TOPSIS, F-PROMETHEE, and F-VIKOR, respectively.

As a result of the application of the fuzzy MCDM approaches the sequence of the alternatives is formed with respect to rating scores of the alternatives. Table 5 shows the results of the application of F-AHP, F-TOPSIS, F-PROMETHEE and F-VIKOR. For the solution representation, the scores of the alternatives in each solution are normalized to use them analogously in PGP.

Table 5: Results of the application of fuzzy MCDM methods

Fuzzy MCDM Methods	Alternatives				
	***A*1**	***A*2**	***A*3**	***A*4**	***A*5**
F-AHP	0.4065	0.4594	0.0497	0.0000	0.0844
F-TOPSIS	0.2373	0.2524	0.1721	0.1349	0.2034
F-PROMETHEE	0.2848	0.2879	0.1873	0.0000	0.2400
F-VIKOR	0.5856	0.3057	0.0364	0.0181	0.0542

After the application of the fuzzy MCDM approaches, the parameters of the PGP model are organized as shown in Table 6, and the parameter s is set to 2. The weights of the criteria in Table 6 are defined with respect to the prescience of the decision makers. By considering the four different solutions obtained in the first stage, the PGP model is solved for each alternative methods. As a result of the model computations, the alternatives A1 and A2 are obtained as an optimum selection for each solution approach where the objective function values of the optimum solutions are 406.1341, 406.5103, 406.4273, and 406.1087 for the models 1-4, respectively.

Table 6: Problem data for the PGP models

Goals		P_k	a_{ij}					t_i
			***A*1**	***A*2**	***A*3**	***A*4**	***A*5**	
Fuzzy MCDM Method	F-AHP	1	0.4065	0.4594	0.0497	0.0000	0.0844	1.00
	F-TOPSIS		0.2373	0.2524	0.1721	0.1349	0.2034	1.00
	F-PROMETHEE		0.2848	0.2879	0.1873	0.0000	0.2400	1.00
	F-VIKOR		0.5856	0.3057	0.0364	0.0181	0.0542	1.00
Quantitative Criteria	Cost	2	128	66	300	384	160	600
	Capacity	3	5000	2000	7000	8000	4000	10000
	Depreciation	4	0.65	0.35	0.88	1.40	0.44	1.00

6. Discussion and Conclusion

Facility layout planning, is considered as a long-term decision making process and critical for the companies by having potential to increase operational productivity. Therefore, the layout plans have to be formed by considering various qualitative and quantitative criteria. In this study, a SASP of an automotive company is studied as a real-life problem which aims to evaluate best stock area selection from the alternatives by taking into account both qualitative and quantitative criteria. To solve the case study of the company, this paper proposes four solution approaches by integrating a fuzzy MCDM method (F-AHP, F-TOPSIS, F-PROMETHEE and F-VIKOR) within a PGP model. Each solution procedure consists of two stages: First, the problem is solved by using a fuzzy MCDM method to obtain a rate for the alternatives with respect to the qualitative criteria. Then, the problem is solved by using PGP model regarding the results of the fuzzy MCDM scores as a special constraint. In order to identify the final decision for the company the solutions of the solution approaches are compared via the outputs of the PGP model, where the solutions of the approaches are similar. As a result of the computations, second and fourth alternatives are selected as a stock area for the company. According to the selected alternatives, an extra 194 carrier capacity is provided for the company within the investment cost limit. For the future researches this study can be extended by considering the hybrid MCDM methods or the proposed solution methodology can be integrated within a simulation model to analyse performance of the selection stochastically.

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Appendix A. Input data for F-AHP method

Table A1: Comparison matrix for criteria assessed by decision makers

Decision Maker	Criteria	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8
Decision Maker 1	*C*1	E	EW	EW	WF	F	FS	SA	A
	*C*2	1/EW	E	EW	W	WF	F	FS	SA
	*C*3	1/EW	1/EW	E	W	WF	FS	S	A
	*C*4	1/WF	1/W	1/W	E	EW	W	WF	FS
	*C*5	1/F	1/WF	1/WF	1/EW	E	EW	WF	FS
	*C*6	1/FS	1/F	1/FS	1/W	1/EW	E	EW	WF
	*C*7	1/SA	1/FS	1/s	1/WF	1/WF	1/EW	E	EW
	*C*8	1/A	1/SA	1/A	1/FS	1/FS	1/WF	1/EW	E
Decision Maker 2	*C*1	E	1/EW	EW	E	W	FS	WF	SA
	*C*2	EW	E	WF	EW	FS	A	SA	A
	*C*3	1/EW	1/WF	E	1/EW	EW	F	W	F
	*C*4	E	1/EW	EW	E	EW	FS	WF	FS
	*C*5	1/W	1/FS	1/EW	1/EW	E	WF	EW	WF
	*C*6	1/FS	1/A	1/F	1/FS	1/WF	E	1/EW	E
	*C*7	1/WF	1/SA	1/W	1/WF	1/EW	EW	E	EW
	*C*8	1/SA	1/A	1/F	1/FS	1/WF	E	1/EW	E
Decision Maker 3	*C*1	E	EW	EW	WF	W	FS	SA	A
	*C*2	1/EW	E	E	W	EW	WF	FS	SA
	*C*3	1/EW	E	E	WF	W	FS	SA	A
	*C*4	1/WF	1/W	1/WF	E	1/EW	EW	W	WF
	*C*5	1/W	1/EW	1/W	EW	E	W	WF	FS
	*C*6	1/FS	1/WF	1/FS	1/EW	1/W	E	W	WF
	*C*7	1/SA	1/FS	1/SA	1/W	1/WF	1/W	E	EW
	*C*8	1/A	1/SA	1/A	1/WF	1/FS	1/WF	1/EW	E

Table A2: Comparison matrix of alternatives with respect to the criteria assessed by decision makers

		Decision Maker 1					Decision Maker 2					Decision Maker 3				
Criteria	**Alternatives**	***A*1**	***A*2**	***A*3**	***A*4**	***A*5**	***A*1**	***A*2**	***A*3**	***A*4**	***A*5**	***A*1**	***A*2**	***A*3**	***A*4**	***A*5**
*C*1	*A*1	E	1/EW	SA	A	EW	E	EW	WF	SA	WF	E	1/F	E	WF	1/W
	*A*2	EW	E	FS	SA	WF	1/EW	E	FS	SA	FS	F	E	W	S	EW
	*A*3	1/SA	1/FS	E	FS	1/WF	1/WF	1/FS	E	FS	E	E	1/W	E	WF	1/EW
	*A*4	1/A	1/SA	1/FS	E	1/F	1/SA	1/SA	1/FS	E	1/FS	1/WF	1/s	1/WF	E	1/WF
	*A*5	1/EW	1/WF	WF	F	E	1/WF	1/FS	E	FS	E	W	1/EW	EW	WF	E
*C*2	*A*1	E	1/W	SA	A	WF	E	EW	FS	SA	EW	E	1/EW	E	W	1/EW
	*A*2	W	E	FS	SA	WF	1/EW	E	W	FS	E	EW	E	FS	SA	E
	*A*3	1/SA	1/FS	E	FS	1/W	1/FS	1/W	E	WF	1/W	E	1/FS	E	WF	1/EW
	*A*4	1/A	1/SA	1/FS	E	1/EW	1/SA	1/FS	1/WF	E	1/F	1/W	1/SA	1/WF	E	1/WF
	*A*5	1/WF	1/WF	W	EW	E	1/EW	E	W	F	E	EW	E	EW	WF	E
*C*3	*A*1	E	EW	SA	A	WF	E	EW	E	WF	EW	E	EW	EW	WF	EW
	*A*2	1/EW	E	FS	SA	WF	1/EW	E	1/W	WF	E	1/EW	E	E	WF	E
	*A*3	1/SA	1/FS	E	WF	1/WF	E	W	E	SA	W	1/EW	E	E	WF	E
	*A*4	1/A	1/SA	1/WF	E	1/W	1/WF	1/WF	1/SA	E	1/WF	1/WF	1/WF	1/WF	E	1/WF
	*A*5	1/WF	1/WF	WF	W	E	1/EW	E	1/W	WF	E	1/EW	E	E	WF	E
*C*4	*A*1	E	EW	FS	A	WF	E	1/W	E	WF	1/W	E	E	FS	A	W
	*A*2	1/EW	E	F	SA	W	W	E	W	FS	E	E	E	FS	A	W
	*A*3	1/FS	1/F	E	F	1/W	E	1/W	E	WF	1/W	1/FS	1/FS	E	F	1/W
	*A*4	1/A	1/SA	1/F	E	1/EW	1/WF	1/FS	1/WF	E	1/FS	1/A	1/A	1/F	E	1/F
	*A*5	1/WF	1/W	W	EW	E	W	E	W	FS	E	1/W	1/W	W	F	E
*C*5	*A*1	E	W	FS	SA	WF	E	EW	FS	A	WF	E	E	FS	A	E
	*A*2	1/W	E	F	S	W	1/EW	E	FS	SA	WF	E	E	S	A	E
	*A*3	1/FS	1/F	E	F	1/W	1/FS	1/FS	E	WF	1/W	1/FS	1/s	E	WF	1/FS
	*A*4	1/SA	1/s	1/F	E	1/WF	1/A	1/SA	1/WF	E	1/WF	1/A	1/A	1/WF	E	1/A
	*A*5	1/WF	1/W	W	WF	E	1/WF	1/WF	W	WF	E	E	E	FS	A	E
*C*6	*A*1	E	WF	SA	SA	S	E	1/WF	WF	WF	1/W	E	W	A	SA	S
	*A*2	1/WF	E	FS	FS	F	WF	E	FS	FS	EW	1/W	E	S	FS	F
	*A*3	1/SA	1/FS	E	E	1/EW	1/WF	1/FS	E	E	1/WF	1/A	1/s	E	1/W	1/EW
	*A*4	1/SA	1/FS	E	E	1/EW	1/WF	1/FS	E	E	1/WF	1/SA	1/FS	W	E	1/W
	*A*5	1/s	1/F	EW	EW	E	W	1/EW	WF	WF	E	1/s	1/F	EW	W	E
*C*7	*A*1	E	1/W	FS	SA	WF	E	1/WF	1/SA	1/S	WF	E	1/W	FS	WF	FS
	*A*2	W	E	S	A	F	WF	E	1/W	1/WF	F	W	E	SA	F	SA
	*A*3	1/FS	1/s	E	WF	1/W	SA	W	E	1/EW	S	1/FS	1/SA	E	1/W	E
	*A*4	1/SA	1/A	1/WF	E	1/F	S	WF	EW	E	FS	1/WF	1/F	W	E	W
	*A*5	1/WF	1/F	W	F	E	1/WF	1/F	1/s	1/FS	E	1/FS	1/SA	E	1/W	E
*C*8	*A*1	E	EW	1/F	1/WF	1/F	E	EW	E	SA	WF	E	FS	WF	E	SA
	*A*2	1/EW	E	1/WF	1/W	1/WF	1/EW	E	1/EW	S	W	1/FS	E	1/WF	1/FS	EW
	*A*3	F	WF	E	1/EW	1/EW	E	EW	E	SA	WF	1/WF	WF	E	1/WF	WF
	*A*4	WF	W	EW	E	EW	1/SA	1/s	1/SA	E	1/WF	E	FS	WF	E	SA
	*A*5	F	WF	EW	1/EW	E	1/WF	1/W	1/WF	WF	E	1/SA	1/EW	1/WF	1/SA	E

Appendix B. Input data for F-TOPSIS

Table B1: The importance weight of the criteria assessed by decision makers

Criteria	Decision Maker 1	Decision Maker 2	Decision Maker 3
*C*1	VH	H	VH
*C*2	H	VH	H
*C*3	H	MH	H
*C*4	MH	H	M
*C*5	M	M	MH
*C*6	ML	L	ML
*C*7	L	ML	L
*C*8	ML	L	ML

Table B2: The ratings of the five alternatives according to all criteria assessed by decision makers

Criteria	Alternatives	Decision Maker 1	Decision Maker 2	Decision Maker 3
*C*1	*A*1	H	VH	MH
	*A*2	VH	H	VH
	*A*3	ML	M	MH
	*A*4	VL	ML	L
	*A*5	MH	M	H
*C*2	*A*1	H	VH	M
	*A*2	VH	H	MH
	*A*3	ML	MH	M
	*A*4	ML	L	VL
	*A*5	M	H	MH
*C*3	*A*1	MH	H	VH
	*A*2	M	MH	M
	*A*3	MH	H	M
	*A*4	ML	L	L
	*A*5	H	MH	M
*C*4	*A*1	VH	MH	H
	*A*2	VH	H	H
	*A*3	MH	MH	M
	*A*4	ML	VL	L
	*A*5	M	H	MH
*C*5	*A*1	VH	MH	H
	*A*2	VH	H	H
	*A*3	M	ML	MH
	*A*4	ML	VL	L
	*A*5	MH	M	H
*C*6	*A*1	H	MH	H
	*A*2	H	H	VH
	*A*3	M	ML	M
	*A*4	ML	ML	MH
	*A*5	MH	H	M
*C*7	*A*1	MH	M	H
	*A*2	M	MH	M
	*A*3	H	VH	MH
	*A*4	VH	H	H
	*A*5	M	ML	L
*C*8	*A*1	MH	H	H
	*A*2	H	MH	VH
	*A*3	MH	H	M
	*A*4	ML	L	L
	*A*5	M	MH	M

Appendix C. Input data for F-PROMETHEE

Table C1: Criteria weights assessed by decision makers

***C*1**	***C*2**	***C*3**	***C*4**	***C*5**	***C*6**	***C*7**	***C*8**
0.1584	0.1881	0.1683	0.1485	0.1287	0.0792	0.0693	0.0594

Table C2: Performance evaluations for the alternatives assessed by decision makers

Decision Maker	Alternatives	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8
Decision Maker 1	*A*1	A	A	LA	SA	SA	A	LA	LA
	*A*2	SA	SA	NC	SA	SA	A	NC	A
	*A*3	LDA	LDA	LA	LA	NC	NC	A	LA
	*A*4	SDA	LDA	DA	LDA	LDA	LDA	SA	DA
	*A*5	LA	NC	A	NC	LA	LA	NC	NC
Decision Maker 2	*A*1	SA	SA	A	LA	LA	LA	NC	A
	*A*2	A	A	LA	A	A	A	LA	LA
	*A*3	NC	LA	A	LA	DA	LDA	SA	A
	*A*4	LDA	DA	DA	SDA	SDA	LDA	A	DA
	*A*5	NC	A	LA	A	NC	A	LDA	A
Decision Maker 3	*A*1	LA	NC	SA	A	A	A	A	A
	*A*2	SA	LA	NC	A	A	SA	NC	SA
	*A*3	LA	NC	NC	NC	LA	NC	LA	NC
	*A*4	DA	SDA	DA	DA	DA	LA	A	DA
	*A*5	A	LA	NC	A	A	NC	DA	NC

Appendix D. Input data for F-VIKOR

Table D1: Importance weight of criteria assessed by decision makers

Decision Makers	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8
Decision Maker 1	ML	H	H	MH	M	ML	L	L
Decision Maker 2	H	VH	MH	H	M	L	ML	L
Decision Maker 3	VH	H	H	M	MH	ML	L	L

Table D2: Rating of alternatives with respect to criteria assessed by decision makers

Decision Maker	Alternatives	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8
Decision Maker 1	*A*1	H	H	MH	VH	VH	H	MH	H
	*A*2	VH	VH	M	VH	VH	H	M	VH
	*A*3	ML	ML	MH	MH	M	M	H	ML
	*A*4	VL	ML	L	ML	ML	ML	VH	VL
	*A*5	MH	M	H	M	MH	MH	M	MH
Decision Maker 2	*A*1	VH	VH	H	MH	MH	MH	M	H
	*A*2	H	H	MH	H	H	H	MH	MH
	*A*3	M	MH	H	MH	L	ML	VH	H
	*A*4	ML	L	L	VL	VL	ML	H	L
	*A*5	M	H	MH	H	M	H	ML	H
Decision Maker 3	*A*1	MH	M	VH	H	H	H	H	H
	*A*2	VH	MH	M	H	H	VH	M	VH
	*A*3	MH	M	M	M	MH	M	MH	M
	*A*4	L	VL	L	L	L	MH	H	L
	*A*5	H	MH	M	H	H	M	L	M